

Key to Acceptable EOR- CCS Systems A Technically Reliable Monitoring and Imaging System



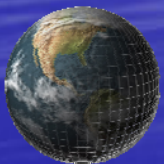
Ernest Majer

Earth Sciences Division
Lawrence Berkeley National Laboratory
Berkeley, California


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Outline

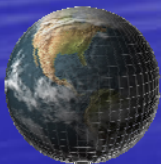
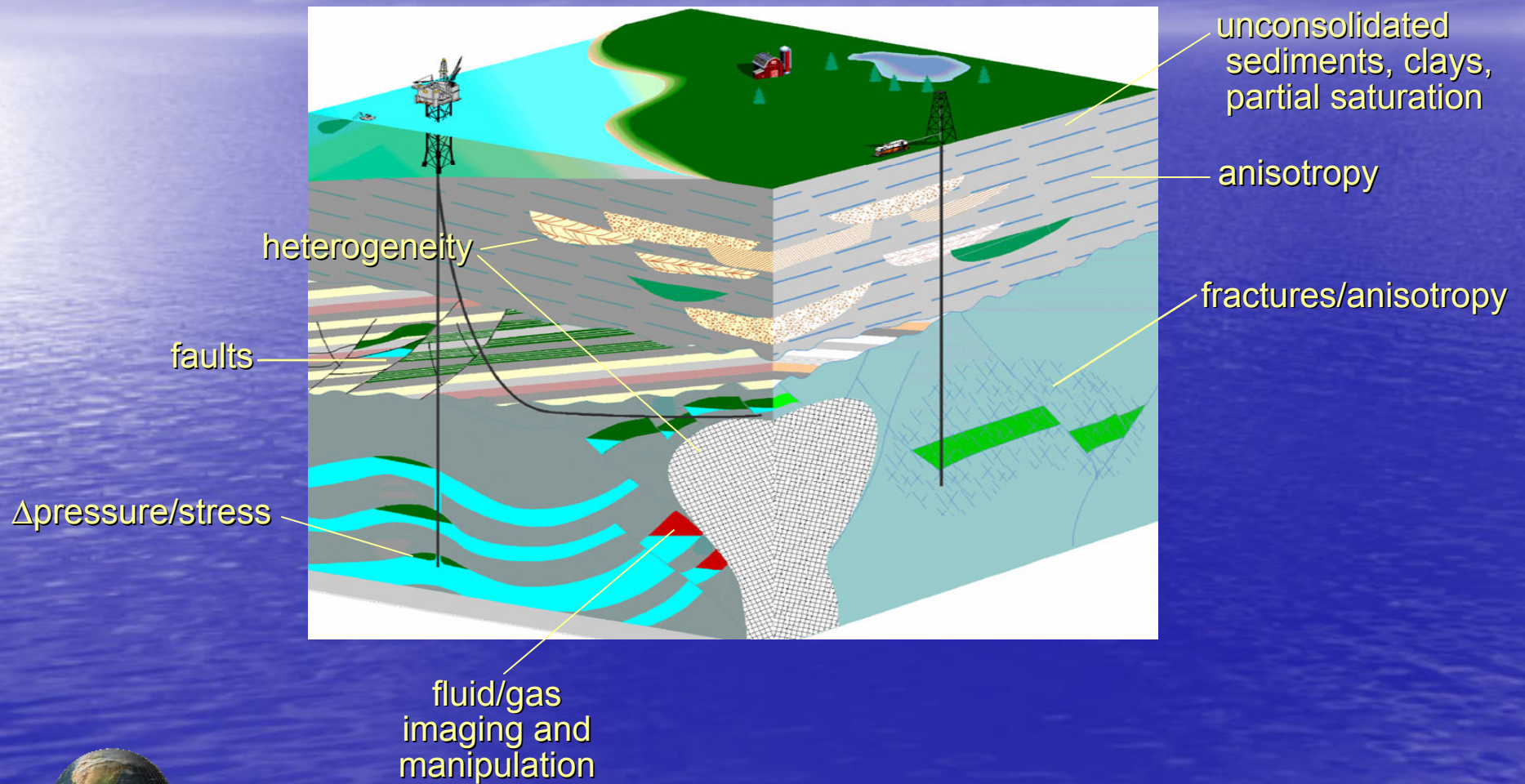
- Motivation
- Challenges and Needs
- Monitoring Protocol
- Example (Active and passive monitoring using microholes)
- Summary and Conclusions



Motivation for Successful Monitoring

- Successful carbon sequestration will be a combination of technology, regulation and public acceptance.
- Energy demand will increase 60% by 2030 over 2000 levels (IEA, DOE, ExxonMobil)
- Fossil energy will remain the main (80%) supply for energy for at least 30 and possibly 50 years
- Bottom Line to the public will be a trade off of economic risks (leaving in ground versus atmosphere)
- “Fossil fuels’ increasing scarcity is not going to rein in emissions growth by itself. To the contrary, there will be a problem for climate-change policies if they induce significant falls in fossil-fuel prices. That is one reason why carbon capture and storage technology is so important”. (Stern Report 2007)
- Mitigation must start now, and to have a significant impact the volumes sequestered must be orders of magnitude greater than today.(1 to 2 Gtons/year)
- In the near term the only option that has the infrastructure to sequester large volumes is the oil and gas industry, i.e decades of development.
-  Ultimate cost must include savings due to avoidance of costs of Climate change.

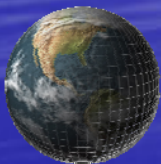
Technical Challenges In Fluid Imaging and Manipulation



Crosscutting Technical Issues for Successful CO₂ Monitoring

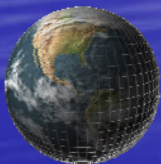
- Basic Need
 - Monitor location and quantity of CO₂
 - Monitor containment of CO₂
 - Establish and evaluate risks
- Fundamental Obstacles
 - Lack of data on the the distribution of rock and fluid properties.
 - Porosity, permeability, lithology and structure
 - Liquid, gas, oil, water content and ratio, etc.
 - Dynamic response of reservoir components as it is produced
 - State of Stress
 - Fluid redistribution and change of state
 - Fracture creation/opening/closure

Must recognize that reservoirs are constantly changing and we must have a means to identify and measure the success of fluid manipulation



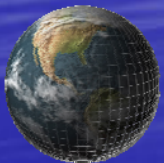
Status

- Seismic methods
 - Active (fluid imaging)
 - Passive (Microearthquake monitoring)
- Non seismic
 - Electrical
 - Magnetic
 - Gravity
 - Direct Detection (gas sampling)
 - Remote sensing



Basic Requirements of Monitoring

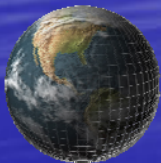
- **Repeatability and stability of measurements**
- **Multiscale**
- **Reliability over long time periods**
- **Accepted history and experience in industry**
- **Developed rock-physics models**
- **Ability to measure and separate rock and fluid properties**



A Basis for a Monitoring Protocol

- Technical
 - Identify and understand factors controlling subsurface dynamics
- Community Interaction
 - Inform and interact with the community to understand their concerns and partner with them to achieve a win-win situation

Both are linked and overlapping



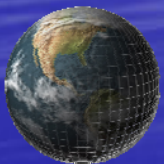
Technical Considerations While Planning

- injection pressure
- volume of injection
- rate of injection
- temperature of fluids
- chemistry of fluid
- continuity of injection
- location and depth of injections
- in-situ stress magnitudes and patterns
- fracture/permeability of rocks
- historical seismicity

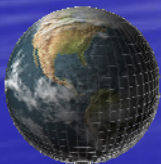


Community Interaction

- Independent third-party evaluation covering the following key items:
 - Background seismicity and potential for large earthquakes
 - Likelihood of induced seismicity
 - Local geologic conditions that may amplify seismic shaking
 - Construction quality of local buildings
 - Validity of proponent's induced seismicity monitoring and mitigation plan.

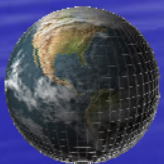


- Early and frequent communication with neighboring communities to:
 - Inform them about project scope and the possibility of induced seismicity.
 - Overview of 3rd-party evaluation (above)
 - Induced seismicity in the context of other known and potential environmental impacts of the EGS project
 - Offsetting benefits (clean source of energy, jobs, tax revenues, etc)
 - If appropriate, the community acceptance program may include donations in support of projects that benefit the community.

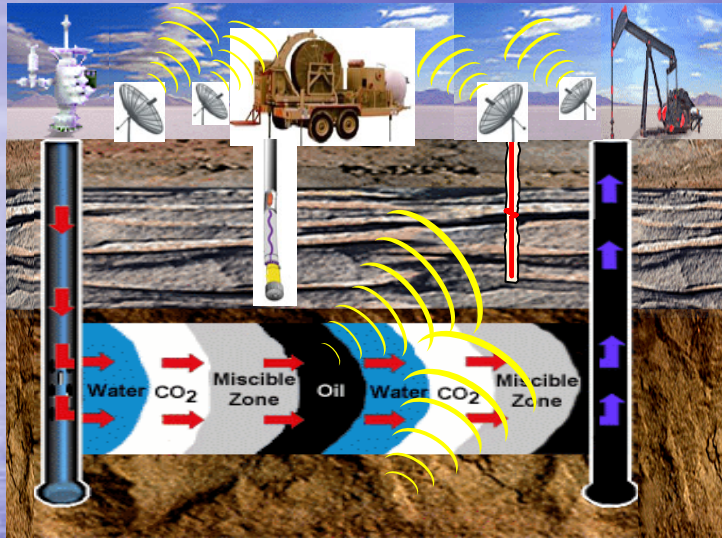


Examples

- Deep imaging and characterization with microhole technology (EOR)
- Injection monitoring with microearthquake methods (Enhanced Geothermal Systems)



Microhole Technologies Specific Focus Areas



"Designer Seismic"
For New E&P Imaging Paradigms

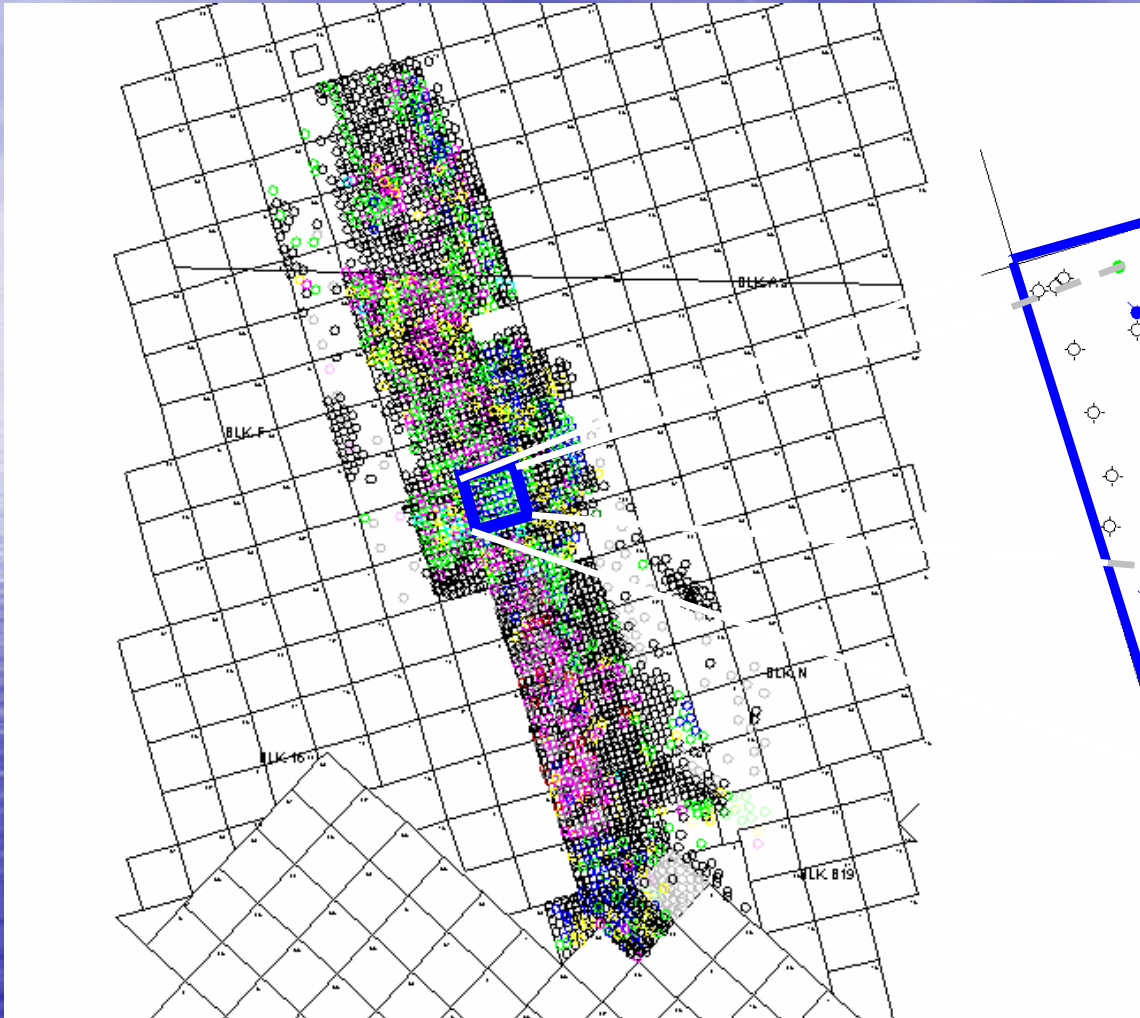


Access: Highly Efficient Rigs
For Mature Field Development

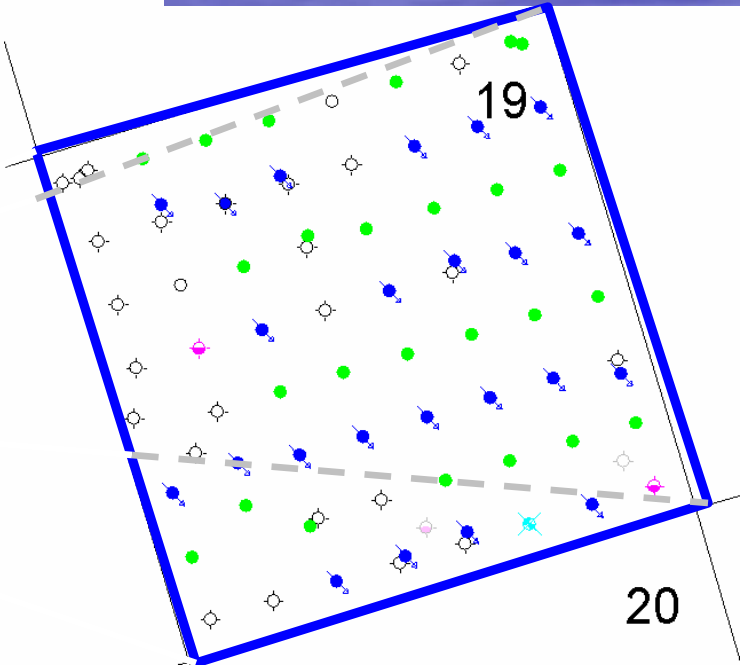
- **To allow a new wave of development drilling for mature fields based on drilling cost reductions approaching 50%**
- **Low environmental impact for improved sensitive area access**
- **New paradigms in "high-res", long term seismic imaging to reduce risk**

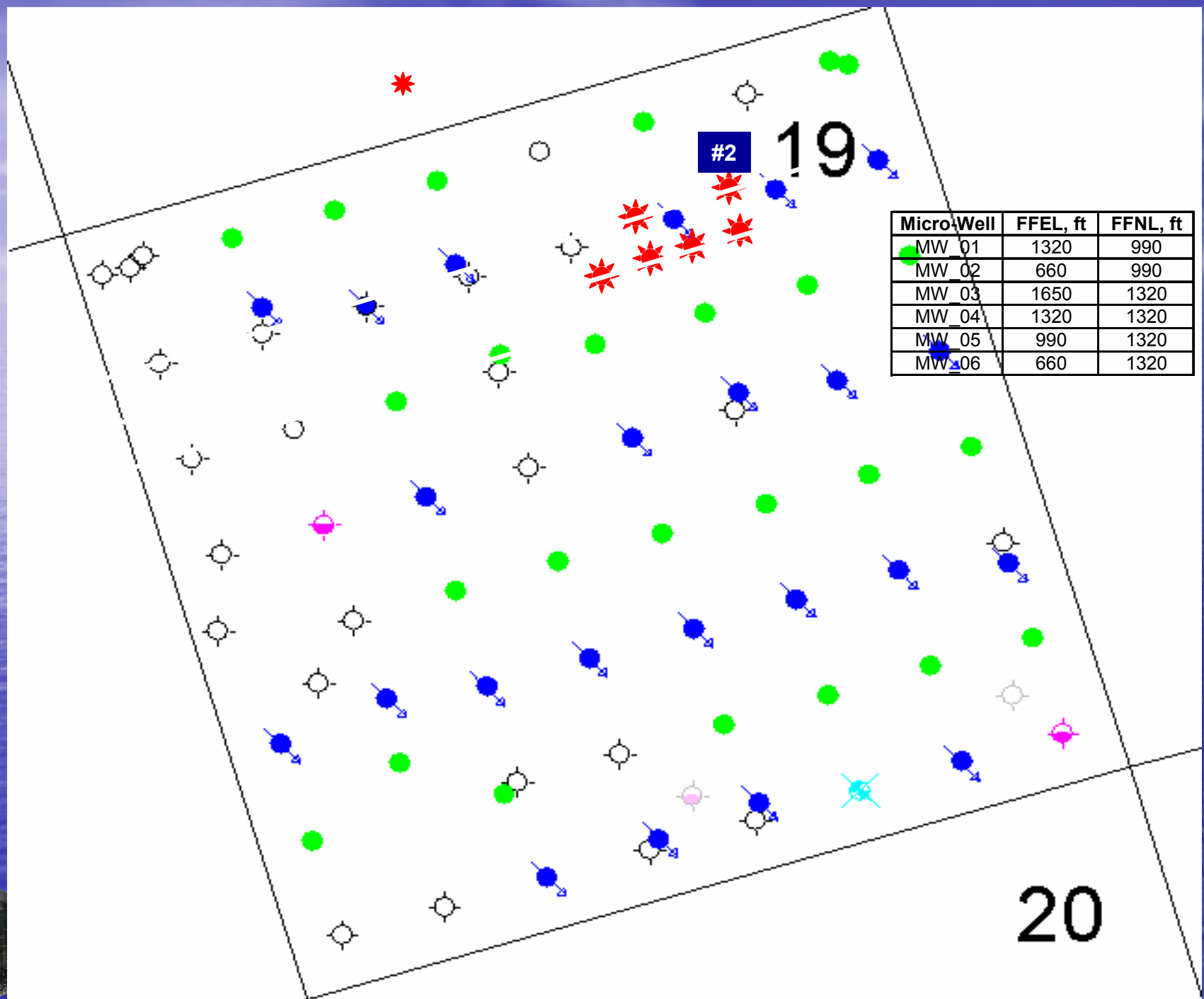


Wickett Field

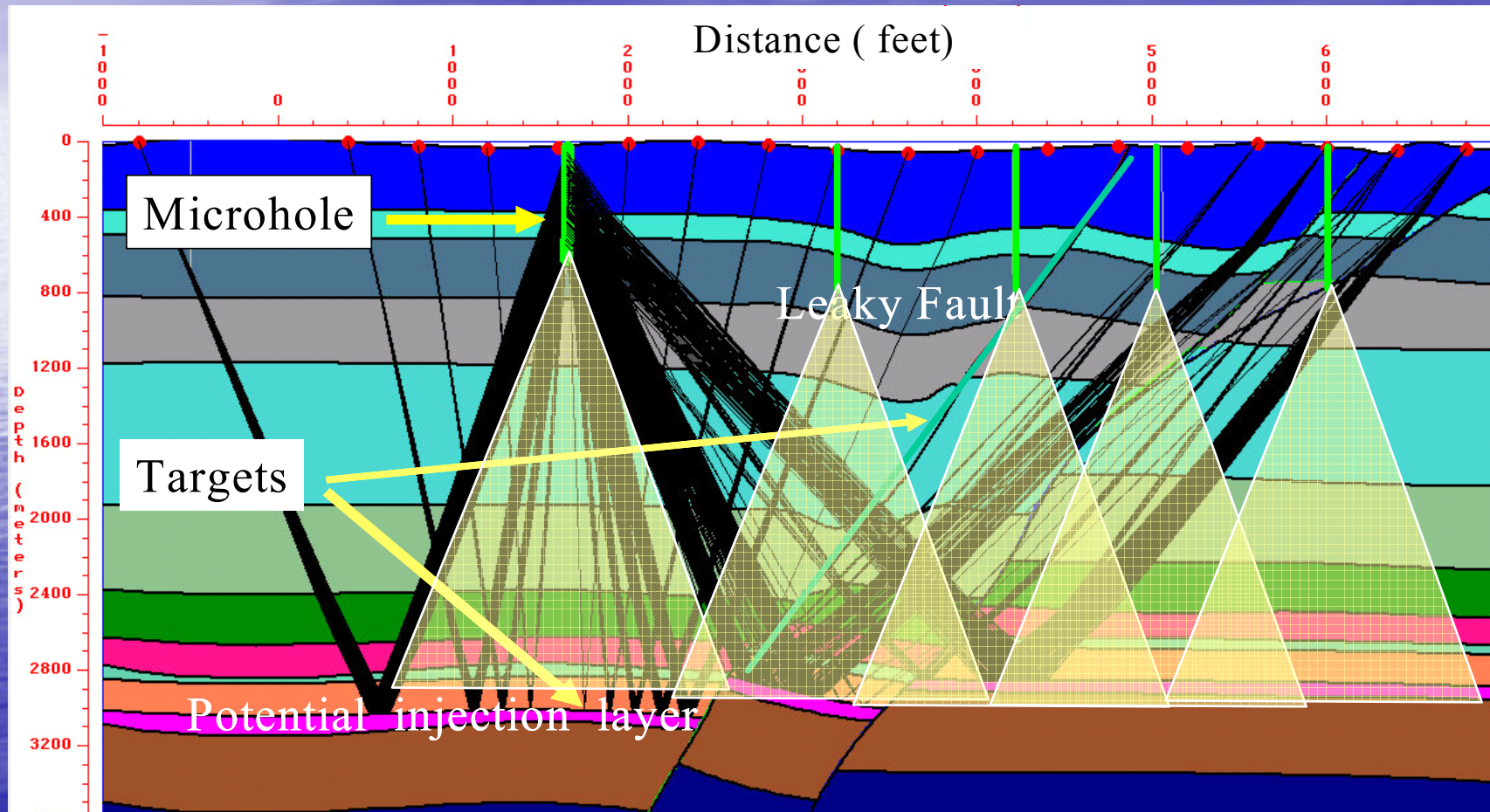


**CO2 Start-Up Area (Phase 1),
Section 19 of GWO Lease**

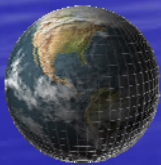
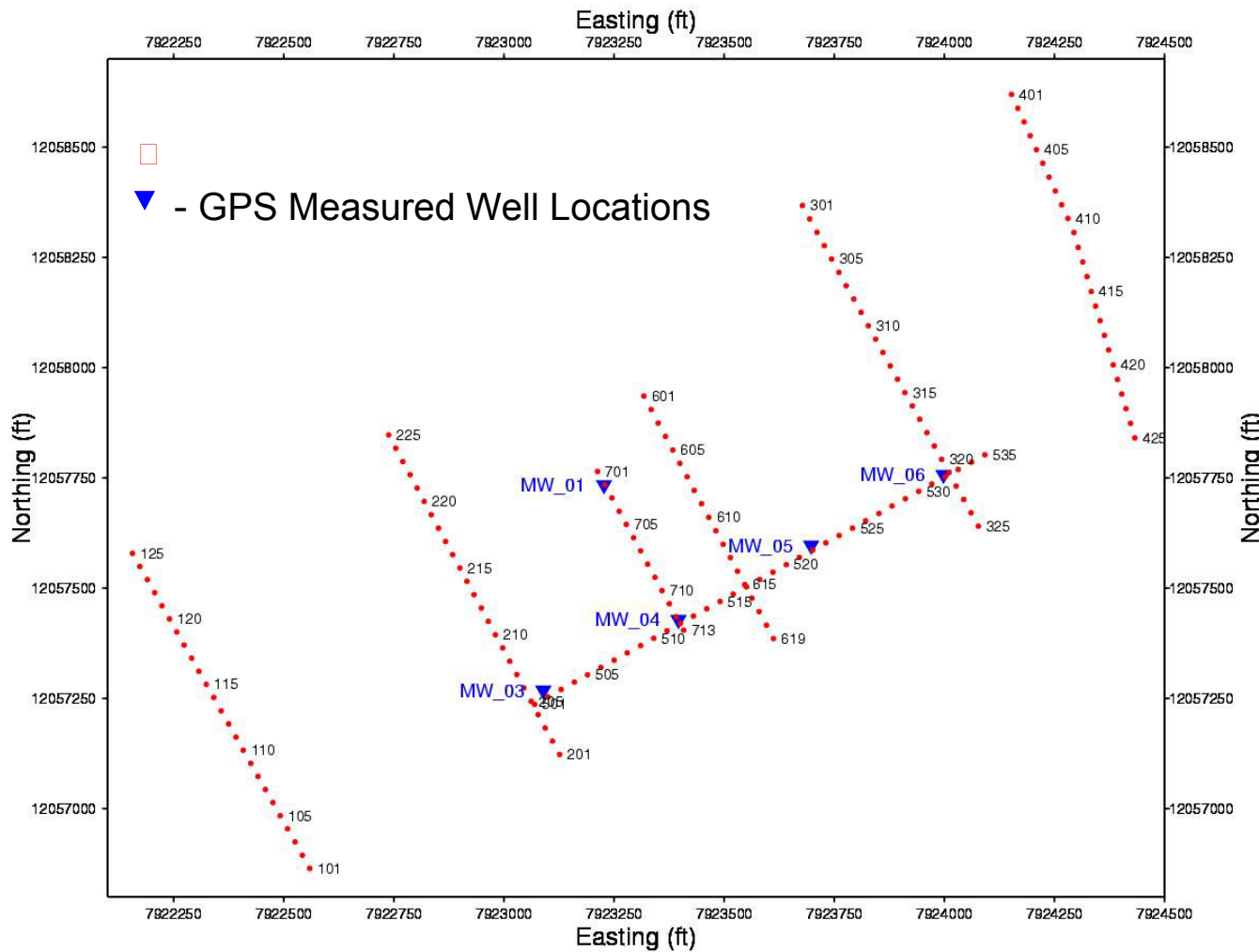




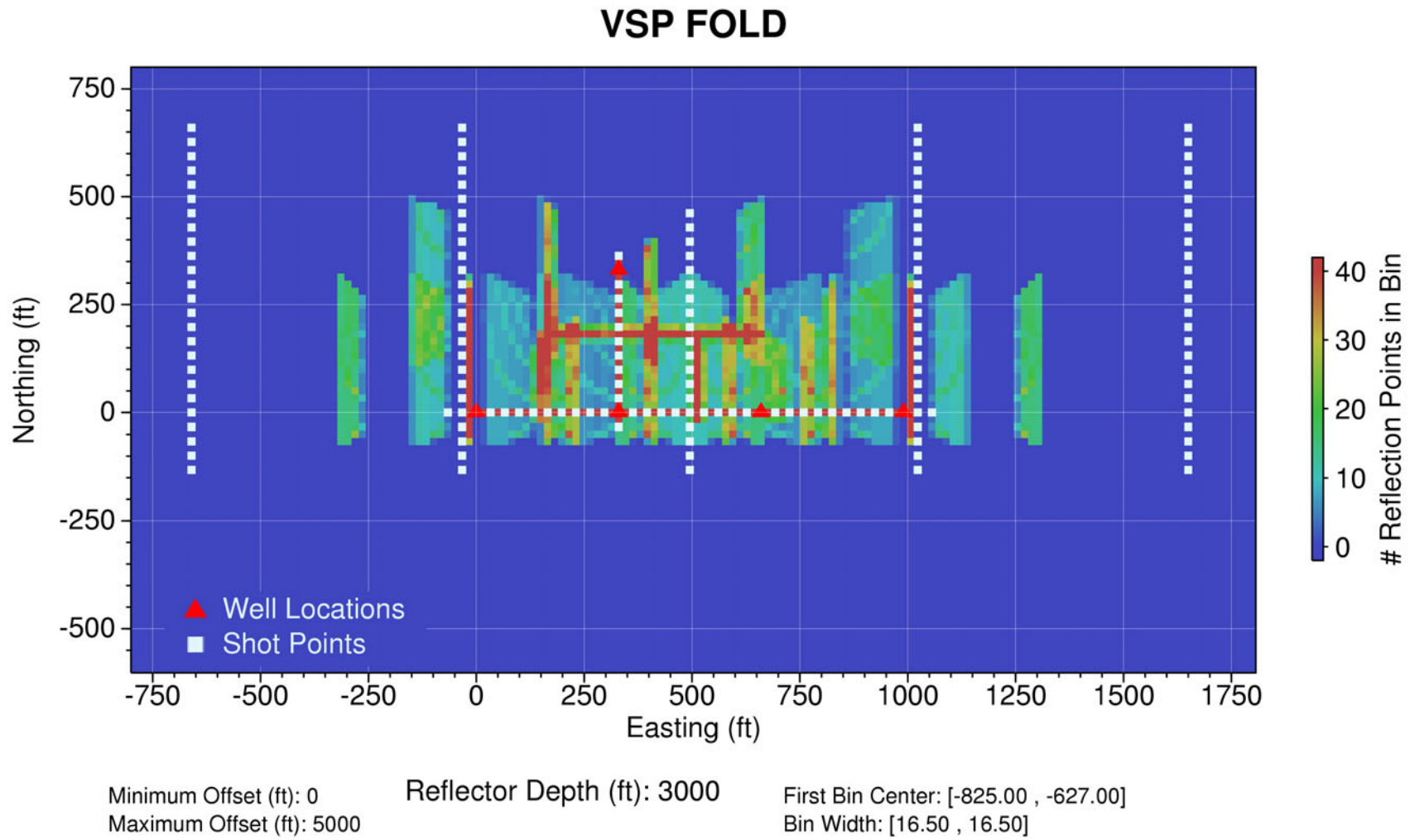
Basis of Imaging Work ; Establish Potential of Deep Characterization Using Microholes



Final Basemap Plot

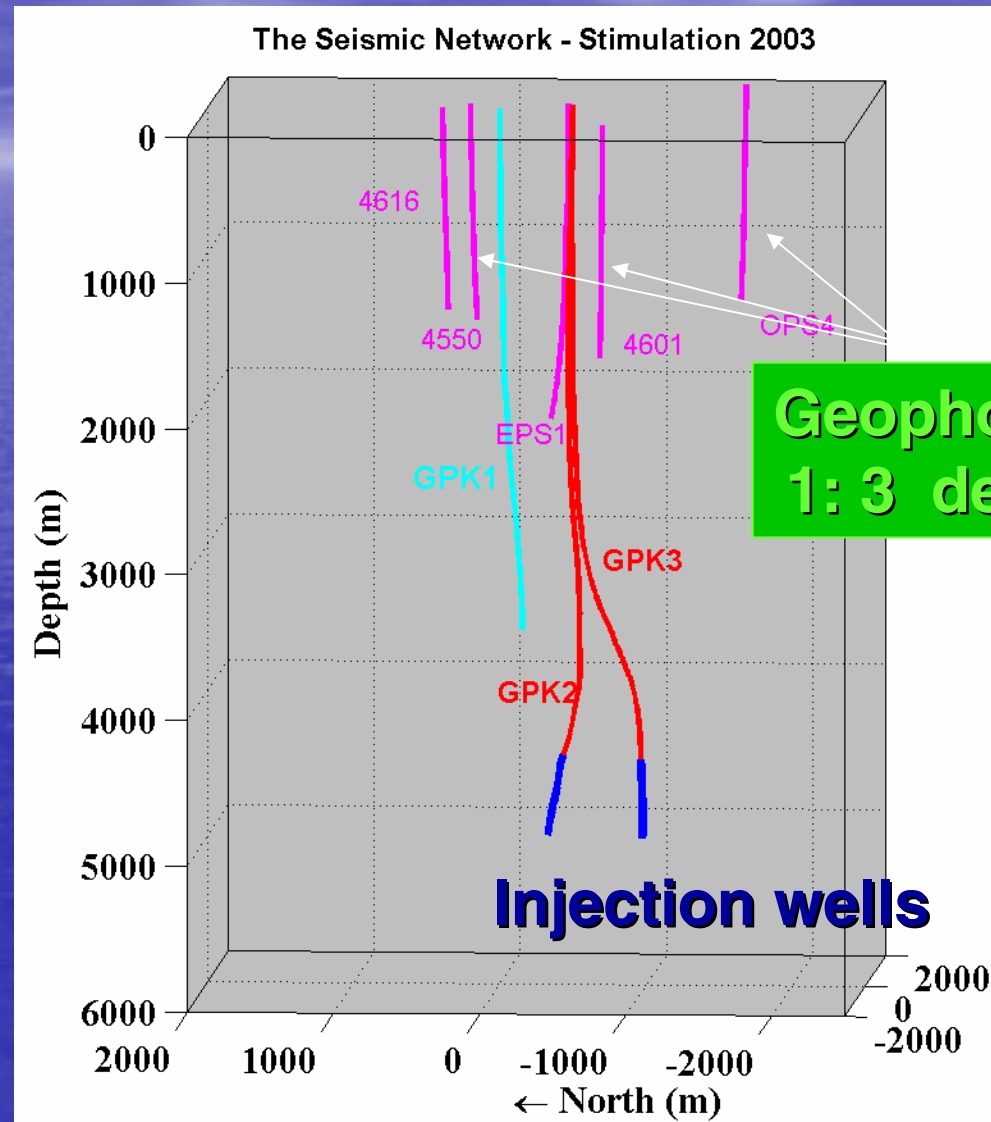


Coverage at Injection Depth (3000ft)



Borehole Seismic Network For Injection Monitoring

3 accelerometers
+
2 geophones
were recording
microseismic events
during the stimulation



From Michelet, 2005

The History

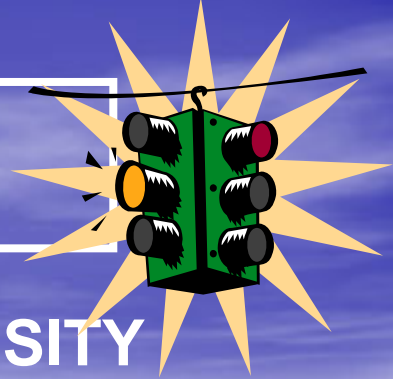
Upper Reservoir
1987 - 1997

Deep Reservoir
1988 - 2003

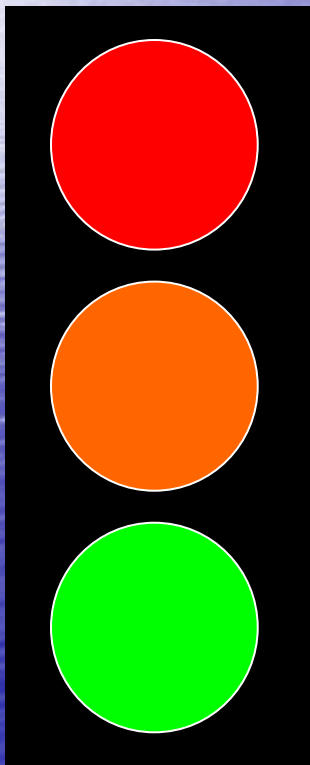
- 1993
- 1995
- 1996
- 2000
- 2003

Able to separate individual injection events

Need for a “Traffic Light” to Control Pumping



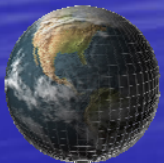
Based on pre-defined thresholds of both **INTENSITY** of induced ground movements and **FREQUENCY** of **OCCURRENCE** of any episodes of shaking.



- Red. The fracc is going out of bounds or seismicity is exceeding acceptable levels. **STOP** and reassess.
- Orange. The fracc is growing away from planned direction or level of seismicity is higher than expected. **CAUTION** – call duty seismologist and be prepared to stop pumping.
- Green. Fracc growth and levels of seismicity within planned bounds. **GO** – everything going according to plan, maintain regular progress reporting

Observations to date

- Active seismic
 - Microhole VSP can look over 5 times hole depth
 - Resolution (due to reduced signal to noise) is better than “conventional” VSP
 - Makes seismic surveys faster and much cheaper
 - Less “invasive” on operations
 - Allows operator to easily customize/change surveys for changing reservoir conditions and varying reservoir conditions across any particular field (“Designer Seismic”)
- Passive Seismic
 - Critical information on fracture generation, fluid interactions and fluid paths can be obtained from borehole seismic data
 - Sensors do not need to be placed at reservoir level
 - Sensors can be placed away from surface and in sufficient azimuthal coverage to eliminate path effects and obtain data for analysis of source mechanisms critical to understanding fracture generation and stress analysis.



Summary and Conclusions

- Technology and infrastructure are available to start sequestration
- There are gaps in understanding the cumulative effect of large scale sequestration
- Technology is available to provide the data and understanding to address the gaps
- Successful large scale monitoring is a combination of technology and public acceptance
- Protocols for monitoring must be established that are based on sound and accepted methods

